TECHNICAL REPORT 2041
April 2014

Demonstration/Validation of a Surface Cleaning Control Practice to Mitigate Storm Water Metal Contaminants

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ADMINISTRATIVE INFORMATION

The demonstration described in this report was conducted under Project 469 of the Navy's Environmental Sustainability Development to Integration (NESDI) Program (http://www.nesdi.navy.mil/) by Environmental Sciences Branch, SPAWAR Systems Center Pacific, San Diego, CA 92152-5000.

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EXECUTIVE SUMMARY

This report describes a demonstration to evaluate the effectiveness of a surface cleaning control practice to remove particles, copper, and zinc from Navy industrial areas in an attempt to mitigate these contaminants in storm water runoff. The evaluation was conducted on multiple Navy piers at Naval Base San Diego (NBSD) between 2011 and 2013. The project evaluated the effectiveness of a commercially available power-washing and power-vacuuming service that can be found in most metropolitan areas. The demonstration was conducted under Project 469 of the Navy's Environmental Sustainability Development to Integration (NESDI) Program (http://www.nesdi.navy.mil/).

The two main goals of the demonstration were to (1) validate the effectiveness of using a high-pressure wash down/recovery and power-vacuum system in reducing copper and zinc particles from Navy industrial pier areas; and (2) validate its effectiveness in meeting National Pollutant Discharge Elimination System (NPDES) storm water compliance requirements. This latter goal is important for Navy facilities that have difficulty in consistently meeting copper, zinc, and toxicity thresholds required in their storm water NPDES permits.

The technical approach to evaluate the effectiveness of particle, copper, and zinc removal was to measure their amounts collected and composited from multiple random areas on half of a pier where the cleaning was applied and compare them to the amounts collected on the other half of the pier where the best management practice (BMP) had not been applied. Ten random sites were chosen from half of three piers where particles were collected weekly with a backpack style high efficiency vacuum cleaner and evaluated for total mass and copper and zinc concentration. The technical approach to evaluate the effectiveness of the surface cleaning control practice in meeting NPDES permit benchmarks was to compare total copper, zinc, and acute toxicity measured in storm water samples collected from each half of the pier during three storm events as part of normal NPDES monitoring.

Results showed that the surface cleaning control practice decreased the loading of particles, copper, and zinc levels on all three piers under varying operational tempos. The particle load reductions ranged from 31 to 70% and were statistically significant for all three piers. On average, the cleaning reduced particle loads between ~ 14 and 20 kg on half of each pier. The average loading of copper and zinc on the piers was substantially if not statistically reduced by 75% and 40%, respectively. In addition to the overall reductions in loading, implementation of the cleaning control practice appeared to reduce spiking of loads even under increasing operational tempos.

The surface cleaning control practice also led to substantial reductions in storm water copper and zinc concentrations. The reductions were not sufficient to meet historical NPDES permit benchmarks of 67 and 113 μg L^{-1} for copper and zinc, respectively, nor the acute toxicity requirement for meeting 90% survival. However, the reductions improve the chances of meeting new NPDES permit action limits that are based on facility-wide average storm water concentrations as well as a new acute toxicity survival value that is no greater than 40% different from control. The benefits for implementing this surface cleaning control practice need to be evaluated against its cost and likelihood for gaining regulatory relief.

NPDES permit requirements for NBSD changed during the execution of this surface cleaning project. The new requirements for NBSD (and soon for all metro bases in Navy Region SW) include meeting a facility-wide annual average Numeric Action Limit (NAL) of 33.2 and 260 μg L^{-1} for copper and zinc, respectively, as well as an acute toxicity limit of > 40% difference from control for individual samples. Failure to meet these limits requires the facility to conduct further evaluations of

the sources, potential control measures, eventually leading to implementation of best available technology economically achievable (BAT). Because surface cleaning substantially reduced storm water concentrations of copper and zinc, it can potentially be a useful control practice in helping meet the average annual facility-wide limits even if individual storm water samples from the piers did not meet NAL values. The use of this control practice may also provide a means for meeting BAT.

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ACRONYMS

BAT	Best Available Technology Economically Achievable
BMP	Best Management Practice
NAL	Numeric Action Limits
NAVFACSW	Naval Facilities Command Southwest
NAVSEA	Naval Sea Systems
NBSD	Naval Base San Diego
NESDI	Navy Environmental Sustainability Development to Integration
NPDES	National Pollutant Discharge Elimination System
SDRWQCB	San Diego Regional Water Quality Control Board
SSC	Space and Naval Warfare Systems Center
TMDL	Total Maximum Daily Load

1. INTRODUCTION

This report describes an evaluation of the effectiveness of using a surface-cleaning best management practice (BMP) to remove particles, copper, and zinc in industrial storm water runoff from Navy industrial areas. The evaluation was conducted on multiple Navy piers at Naval Base San Diego (NBSD) between 2011 and 2013. The project evaluated the effectiveness of a commercially contracted power- washing and power-vacuuming service to reduce particles, copper, and zinc loading on industrial pier areas. The project also evaluated the impact of the BMP in reducing storm water concentrations of copper and zinc and its acute toxicity below industrial storm water permit requirements. The report describes the background, technical approach, methods employed, results and lessons learned. The work was performed under Project 469 of the Navy's Environmental Sustainability Development to Integration (NESDI) Program (http://www.nesdi.navy.mil/).

1.1 BACKGROUND

Navy facility storm water is regulated under Clean Water Act of 1972 National Pollutant Discharge Elimination System (NPDES) permits. The Navy's industrial storm water permits commonly have benchmarks or numeric concentration limits for metals such as copper and zinc that are designed to ensure that water quality standards are met within the water bodies that receive the discharge. The requirements can become even more stringent to meet Total Maximum Daily Load (TMDL) limitations when the discharges are to water bodies that are identified as impaired for the metal (Clean Water Act, 1972). These limits have become more stringent over the last 10 years as a result of an increasing concern over the ability to meet the relatively low receiving water toxic thresholds posed by these metals. More recently, the State of California has added a requirement that storm water also meet an acute toxicity requirement (SDRWQCB, 2013) that commonly fails as a result of elevated copper and zinc concentrations (Katz et al., 2006).

Navy facilities have difficulty meeting compliance with the stricter limits on copper, zinc, and toxicity because they have condensed industrial operations, contain site materials that can be a source of metals, have a high percentage of impervious surface, considerable vehicular traffic, and have very short conveyance distances to reach receiving waters. These particular site conditions can and do lead to relatively high storm water copper and zinc levels relative to benchmarks or limits and commonly fail acute toxicity testing.

Best management practices have been identified and employed around the country to mitigate storm water metal contaminants. These control measures range from simple housekeeping efforts such as moving activities that generate contaminants indoors up to highly sophisticated and expensive storm water capture and treatment systems that remove the contaminants once they are entrained in the storm water. Eliminating or reducing the amount of particles before they ever become entrained into storm runoff can reduce the level of particle-borne contaminants that are discharged and reduces the amount that would need to be captured and/or treated when applying an engineered treatment system. There has been considerable effort by researchers and commercial enterprises to develop BMPs that can be applied to a variety of storm water contaminant issues though their effectiveness has rarely been tested under the unique conditions posed by metal contaminants at Navy facilities.

The need for BMP validation at Navy sites was identified in a "need" submitted to the NESDI Program by Naval Facilities Command Southwest (NAVFACSW) Environmental in November 2010 (Need:N-0760-11). The NESDI need outlined the issue of non-compliance with metal concentrations and toxicity and the potential costs of mitigation. It also identified the specific difficulties in meeting compliance on Navy industrial pier areas and the potential benefit of pier surface cleaning as means

to meet compliance and thereby eliminating or delaying very costly pier reconstruction. In response to the NESDI need, the Environmental Sciences Branch of SPAWAR Systems Center (SSC) Pacific submitted a pre-proposal for validating a surface-cleaning BMP in March 2011. The full proposal was submitted in April 2011, approved in June 2011, and funded in October 2011. The NESDI demonstration project 469 was conducted between November 2011 and November 2013.

2. DEMONSTRATION GOALS

The two main goals of this NESDI demonstration project were to:

1. Validate the effectiveness of using a high-pressure wash down/recovery and power-vacuum system in reducing copper and zinc particles from Navy industrial pier areas
2. Validate the effectiveness of using the surface cleaning BMP in meeting NPDES storm water compliance requirements

The first goal was designed to evaluate if a surface cleaning technique can be effective at reducing the mass loading of contaminants at Navy industrial sites. Effective removal of contaminant loads can be used in meeting requirements under Total Maximum Daily Load compliance scenarios and potentially be used in meeting the general commitment of reducing or eliminating contaminant discharges under NPDES permits. A significant reduction of entrained particles in storm runoff can also serve as a pre-treatment technique for additional control practices. The demonstration, therefore, compared loading levels in industrial areas where the cleaning control practice was applied against similar areas where the cleaning was not applied.

The second goal was designed to answer the question of the applicability of the control practice in meeting specific compliance conditions within NPDES permits. Ultimately, Navy facilities are usually required to meet a contaminant concentration goal or limit in their permits regardless of mitigation steps they take to reduce contaminant loading. The demonstration therefore compared contaminant concentrations measured in storm water discharging from areas where the cleaning control practice was applied against concentrations in discharges from similar areas where the cleaning was not applied.

Two key considerations for the demonstration were to conduct the validation under actual operational conditions at Navy industrial sites and to conduct surface cleaning using power-vacuuming/washing technology commonly available through local vendors.

3. TECHNICAL APPROACH

The demonstration approach was to evaluate commercially available surface cleaning technologies that could be easily implemented by Navy facilities nationwide. There has been considerable research to quantify the benefits of power vacuuming using commercially available street sweepers (Breault, Smith, and Sorenson, 2005; Law, DiBlasi, and Ghosh, 2008; Martinelli, Waschbusch, Bannerman, and Wisner, 2002; Pitt, Bannerman, and Sutherland, 2004; Weston Solutions, 2010). Most have shown a modest benefit in particle removal rates particularly when vacuum technology was applied. Little information existed on the use of power-washing for this purpose, probably because of costs. However, similar commercial vacuuming/power-washing of a non-industrial pier at SSC Pacific showed benefit in meeting compliance requirements[1]. Additional measurements made on the recovered particles from that pier showed that the they contained significant levels of copper and zinc (parts per thousand) and that those particles when contacted with water were a source of dissolved copper and zinc[2]. Additionally, limited testing conducted on a specialized power-washing/recovery unit by the Naval Surface Warfare Center, Carderock Division showed the system was highly effective (> 67%) for particle and metal recovery[3]. Because that system was not available commercially or for testing, the approach was to demonstrate technologies that were available commercially.

The approach to implementing the surface cleaning control practice was to perform weekly power-vacuuming and monthly power-washing/recovery. The combination of the two techniques was required given vendor experience that pre-sweeping eliminated clogging issues during the washing/recovery process. The frequency of implementation was based primarily on implementation costs and logistics, which was mainly to minimize conflicts with pier operations. Consideration was given to altering the frequencies of implementation if the data warranted but there was insufficient costs, manpower, and time required to demonstrate multiple frequency scenarios.

The technical approach to evaluate the effectiveness of particle, copper, and zinc removal was to measure their amounts collected and composited from multiple random areas *on piers where the BMP was applied and compare them to the amounts from areas on the* same pier where the BMP had not been applied. To develop a sufficiently large dataset, this approach was applied to three separate piers with the BMP applied to only one half of each pier. Ten random sites were chosen from each half of a pier where particles were collected weekly with a backpack style, high-efficiency vacuum cleaner and evaluated for total mass and copper and zinc concentration. Additionally, particle size was evaluated to provide insight into the mechanism for control practice effectiveness. The goal was to use data from the weekly measurements to evaluate loading on the pier with and without the control practice during both dry and wet weather conditions.

The technical approach to evaluate the effectiveness of the surface cleaning control practice in meeting NPDES permit benchmarks was to compare total copper, zinc, and acute toxicity measured in storm water samples collected from each half of the pier during three storm events. The storm water collection, chemical, and toxicological analyses were performed by the NAVFACSW storm water contractor as part of the standard storm water monitoring requirements, though the third storm and collecting two samples on both halves of the pier were a slight modification of their standard procedure. This approach allowed for direct comparison of normal storm monitoring data to NPDES permit requirements.

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[1] B. Radsliff. 2010. Personal communication. SPAWAR Systems Center Pacific.
[2] C. Katz. 2007. Unpublished data. SPAWAR Systems Center San Diego.
[3] Naval Sea Systems Command (NAVSEA). 2007. Naval Surface Warfare Center, Carderock Division.

4. METHODS

4.1 DEMONSTRATION SITE

The piers at Naval Base San Diego were chosen as the demonstration site with the help of NAVFACSW Environmental and the NBSD environmental manager and staff. The piers were chosen because these areas have the most stringent requirements under their industrial storm water permit, have commonly failed to meet permit benchmarks, and because other BMP solutions for these areas would likely require large capital costs to implement. The piers are all made of concrete with numerous small drains and/or scuppers that allow storm water to discharge directly to bay waters below. They have bollards and cleats for ship tie-ups, large light poles, and built-in systems including large electrical vaults/panels, fluid handling connection points for sewage, freshwater, ballast water, fire suppression waters, and for high-pressure air and steam piping. These connection points are typically set inside of fixed concrete berms that isolate them from the main pier surface.

Operations on the piers include ship husbandry that includes truck, crane, and forklift operations, minor shipboard painting/depainting, and loading and unloading of ship stores, equipment, and construction materials. The piers also serve as temporary laydown areas for equipment such as diesel generators, blasting systems, compressors, and pumps; for supplies such as ship stores, tools and tool lockers, and paint/depainting gear including blast grit, scaffolding, metal piping and connectors, trailers, miscellaneous hardware; and 55-gal drums and wooden crates/wood storage. Additionally, the piers commonly have trash and recycling dumpsters, gangplanks and stairway structures, porta-potties, and large electrical cables and hoses that are typically left on the piers even when ships are not present. The number and type of materials found on a pier are typically a function of the number of ships present but can vary with the specific operational tempo required by individual ships. The area of laydown, along each side of a pier could be quite dense at times. Only the center 25% area of the pier was always free of laydown.

Three piers were chosen for evaluation: Piers 2, 7, and 13 (Figure 1). These piers were chosen because they represent the range of operations that occur on all the piers and because they have been routinely monitored as part of previous permit requirements. Collectively, pier storm water data have historically failed to meet total copper and zinc benchmarks of 67 and 113 µg/L, respectively as well as acute toxicity limits in samples collected during the first hour of flow (first-flush). The piers failed to meet copper, zinc requirements 78% and 100% (n=46) of the time, respectively. Acute toxicity limits are a more recent addition to the permits and the limits/reporting methods have been modified slightly over the last several years. About 75% of the acute toxicity measurements (n=17) have historically passed this requirement. Results were similar for the other monitored piers with failure rates of roughly 67%, 100%, and 50% for copper, zinc, and toxicity, respectively.

The surface cleaning control practice was applied to one half of each pier to allow for direct comparison against a surface area that was left untreated. Piers 2 and 7 had the BMP implemented on the western or “head” half of the pier, while Pier 13 had the BMP implemented on the eastern or “foot” half of the pier nearest the quay wall. The choice of which pier half was cleaned was dictated by the location of large vault areas that drain directly to the bay. These areas were deemed impractical for the application of the power-washing part of the BMP because there would be no way to ensure full water recovery.

Figure 1. Pier region of Naval Base San Diego used for demonstration/validation of the surface cleaning BMP. Piers 2, 7, and 13 were the specific piers used for evaluation.

4.2 DEMONSTRATION CHRONOLOGY

The demonstration was conducted between January 2012 and May 2013. Particle loading on each of the three piers was evaluated weekly or biweekly during the roughly year and a half period. This effort was usually conducted mid-week using a backpack style vacuum system to collect particles from 20 random locations on each pier (10 on each half). The surface cleaning BMP was implemented between 29 September 2013 and 27 April 2013. Vacuuming was conducted every week during this time. Power-washing was conducted monthly during the same period. All cleaning operations were completed during weekends, usually with vacuuming conducted on Saturdays followed by power-washing/recovery on Sundays. Storm water samples were collected and evaluated for three storm events between January and May 2013. The measurements thus covered two wet weather periods of, roughly October through May, and one period of dry weather in between. There were 11 separate storm events (> 0.05 inches) recorded from January through April 2012 and another 14 from October 2013 through May 2013. The rainfall total measured at the nearby San Diego International Airport during the 2012–2013 wet season was 6.5 inches well below the historic average of 10 inches.

4.3 OBSERVED PIER OPERATIONAL TEMPO

The operational tempo on the piers varied from one another as well as throughout the roughly year and a half observation period. Pier 2 generally had the lowest level of operational activities of the three piers and was relatively low throughout the observation period. The pier commonly had two small ships or fewer with the main activities mostly tied to ship supplies.

Activities on Pier 7 ranged somewhere in the middle of the other two and was a little more variable over the observation period. There were times of relatively high activity in truck and crane traffic and amount of laydown that coincided with a higher number of ships. The activity was generally medium or low during the BMP implementation period. During that time, the pier was undergoing repairs to the concrete surface, resulting in areas that were inaccessible for sampling. The chipping work also led to an increase in the presence of concrete dust and chips that affected the measurements.

Of the three piers, Pier 13 generally had the highest level of operational activities, amount of laydown, and crane and truck traffic as a result of servicing multiple large amphibious landing craft. During the first wet season, the tempo was considerably higher on the eastern end of the pier. The high operational tempo on this pier was reduced to near zero during the summer dry period when no ships were tied up. The tempo increased back up to a very high level in the following wet season during BMP implementation, with the operational tempo a little more evenly distributed along the length of the pier. It should be noted that these observations were made only during the weekly visits and therefore only captured a very minimal timeframe.

4.4 LOADING

4.4.1 Sample Collection

Particles were collected from 20 random locations on each pier. Ten cells were randomly chosen from each half of the pier for sample collection by dividing each pier into 30-ft by 60-ft cells and using a random number generator to pick 20 cells for sampling. The actual locations within a cell were chosen on site in a pseudo-random fashion, with laydown commonly limiting where the location could be set. A painted mark (A-T) was placed onto each location and its Global Positioning System coordinates recorded. The cells and random spray-painted pier markings were the center point for particle collection. Figure 2 shows an example of a grid and random cells used for Pier 13. Particles were collected from within a 1.5- x 1.5-m quadrat constructed of PVC pipe at each of the 20 locations. The exact quadrat sampling location was systematically moved during each weekly visit to

ensure the same location was not vacuumed in consecutive weeks. The quadrat was centered over the painted mark on the pier during the first visit. The quadrat was then moved roughly 1.5 m away from the initial location and placed at various points around the compass (0°, 90°, 180°, etc.) during each subsequent visit. The location was reset to the center after a washing or rain event. Sampling at slightly different locations ensured that the sampling collection was not affected by the previous collection. The planned location for sampling was usually moved when laydown or other operations covered the site. In those instances, the sample location was moved closer. The change in location was consistent with the goal of not resampling the sample place on repeat visits. On each half of the piers, 36 to 38 samples were collected, roughly 12 samples each during the first wet season, the dry season, and the second wet season when the surface-cleaning BMP was implemented.

The area within the quadrat was vacuumed using a Goodway BPV-100 backpack style vacuum equipped with a 1-μ disposable filter bag. Each quadrat was vacuumed for approximately 1 min, 30 sec in each of two directions perpendicular to each other. Ten locations on each half of the pier were vacuumed into one bag. The vacuum bags were sealed with tape and then weighed prior to and after collection to determine the amount of particles collected. They were stored in 1-gal zip-top bags before and after collection to ensure cleanliness.

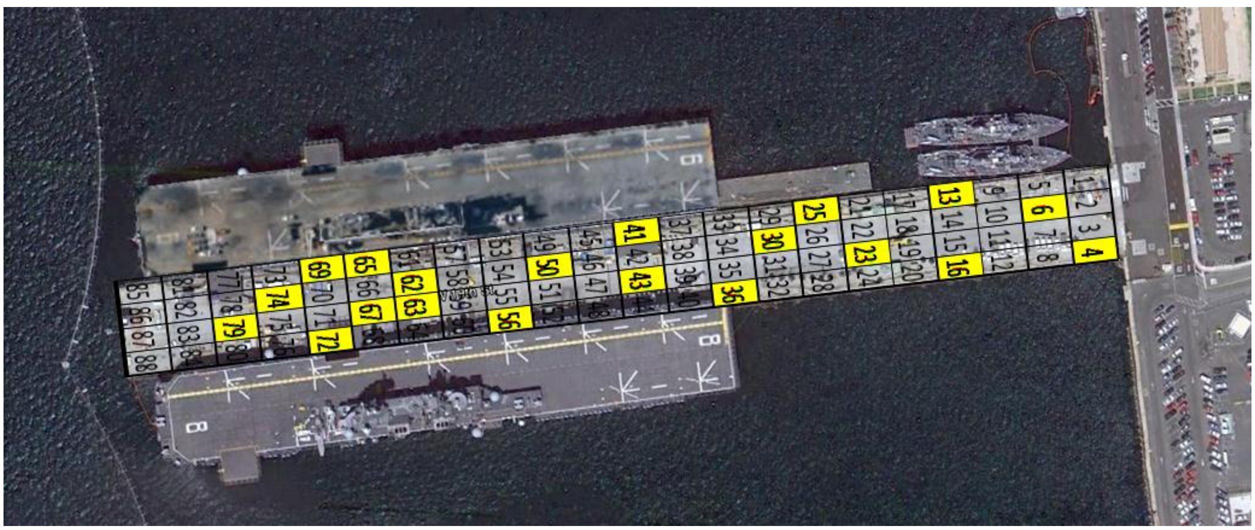


Figure 2. Example of random cells (colored) picked with a random number generator from a uniform grid on Pier 13. Particle sampling was conducted at sites within each of the random cells.

4.4.2 Sample Mass and Grain Size Analysis

Particle samples collected from each half of a pier were analyzed for total mass and mass as a function of grain size. The difference in weight measured before and after collection was used as the total mass. The total mass and total area of collection (10 x 1.5 m^2) allowed calculation of mass/unit area. The vacuum bags were then cut open and the contents deposited into a bowl for mixing. The bag was swept out with a fine brush to release any of the fine particles entrained in the surface of the vacuum bag. Additionally, the bag was weighed after the particles were dumped to account for any loss associated with particles being trapped in the bag. These losses averaged less than 4% of the total collected. The particles were then well mixed to create a homogeneous sample. A subsample (~ 0.2g) was removed for metals analysis. The remaining particles were passed through a series of sieves of 1-mm, 250 μm, 125 μm, and 63 μm. Each size fraction was then weighed and then transferred to a small zip-top bag for storage. The sieve analysis generated five grain size bins of

> 1 mm, 1 mm to 250 µm, 250 to 125 µm, 125 to 63 µm, and < 63 µm. Approximately half way through the study it was decided to eliminate the 125-µm sieve fraction because the data showed little variation from the adjacent bins. The removal of this sieve resulted in only four size bins and a new bin range of 250 to 63 µm.

4.4.3 Particle Metal Analysis

Pier particle subsamples were then analyzed for copper and zinc concentrations. Approximately 0.2 g were removed from the homogenized sample prior to grain size analysis and added to a pre-weighed 125-ml low density polyethylene (LDPE) bottle. The particles were digested with 1.0 ml of concentrated trace metal grade (TMG) hydrochloric acid and 0.5ml of concentrated TMG nitric acid. The samples sat at room temperature for 24 hrs and then were warmed on a hot plate for 1 hr. After the sample cooled, the bottle was filled to the neck with 1 N TMG nitric acid and the final mass was recorded. The digestate was then diluted with 1N quartz-still grade nitric acid for analysis with inductively coupled plasma mass spectrometry (ICP-MS).

Metal concentrations in the digestate were measured with a Perkin-Elmer™ SCIEX ELAN DRC II inductively-coupled plasma with detection by mass spectrometry (ICP-MS) (USEPA 1994). As necessary samples were diluted with 1 N Q-HNO_3 made up in 18 MΩ cm^{-1} water. The diluted samples were injected directly into the ICP-MS via a PerkinElmer™ Autosampler 100. Analytical standards were made with PerkinElmer™ multi-element standard solution (PEMES-3) diluted in IN Q-HNO_3, and were analyzed at the beginning and end of each run. The analysis also included measurement of the Standard Reference Material (SRM) 1643e with recoveries within 15%. The method limit of detection, defined as three times the standard deviation of the procedural blanks made of 1N Q-HNO_3, was 0.5 µg L^{-1}.

4.5 SURFACE CLEANING

Power-vacuuming and power-washing/recovery was performed by Day and Night Power Sweeping, Inc. of El Cajon, California. The contractor was the minimum bidder on a contract request for proposal (RFP) that was generated by the SSC Pacific contracts office and based on a statement of technical work developed specifically for the project. A copy of the statement of work is provided in Appendix A. The basic requirements were to provide weekly power-vacuuming that included the use of a hand-held blower to move particles from the sides of the pier, as well as from in between laydown areas, toward the center of the pier where a vacuum truck could be used to pick up the particles. The presence of large areas of laydown, trucks, dumpsters, cables etc. resulted in some areas that could not effectively be cleaned of particles. The hand blower was used in a manner to minimize the amount of material that would be blown up in to the air and potentially not recovered.

Power-washing was conducted in similar fashion by using a high-pressure sprayer (~ 2000 psi) to wash particles from the sides and laydown areas of the piers towards the center and/or low spots on the pier where a vacuum recovery system could pick up the water and particles. All drains were covered prior to spraying of water to ensure there were no releases to the bay. Water recovery included the use of hand blower and/or large squeegees to move the water and particles toward the vacuum recovery system. The recovery resulted in minimal amount of puddling.

Power-vacuuming always preceded power-washing, though in some instances the two activities were conducted on the same day and in other instance occurred a day apart. All work was performed during weekends to minimize the potential for conflicts with other pier operations. The weekend work eliminated all but a few of these conflicts. There was only one instance when a conflict delayed work sufficiently to result in an incomplete cleaning operation.

4.6 STORM WATER

Storm water sampling of pier runoff was conducted during three storms events by AMEC, San Diego, California. Samples were collected during the first hour of flow using procedures developed to meet NPDES permit requirements. Storm water was composited from two locations on each half of each pier from passive inserts placed into pier deck drains. Water collected in the two drain inserts were emptied into a single HDPE-lined 5-gal bucket. The composited water sample was then split into pre-cleaned sample containers for the measurement of total metals and acute toxicity. The samples were provided to Orange Coast Analytical for total metals analysis and to Nautilus Environmental for acute toxicity analysis. The chain of custody, technical memo, and analytical results from the storm water sampling are provided in Appendix B.

5. RESULTS

5.1 PARTICLE LOADING

5.1.1 Pier 2

Particle loading measurements made throughout the demonstration period on Pier 2 are shown in Figure 3 (full data set can be found in Appendix D). The time series data show relatively similar loading levels on both the west and east halves of the pier during the first wet season and subsequent dry period. Overall, the loading on this pier was the lowest of the three and showed the least variability, consistent with the observed low operational activity. Values commonly ranged between ~ 3 and 4 g m^{-2} at the start of the wet season but dropped off closer to 1.5 g m^{-2} toward the end of March after a relatively large (0.64-inch) storm event. The loading over the entire pier during the first wet season averaged 2.68 g m^{-2} (Table 1, Figure 5). Particle loading on the pier increased into the dry season when levels ranged between ~ 3 and 5 g m^{-2} and averaged 3.71 g m^{-2} over the entire pier. The average wet weather values represent a statistically significant ($p=0.05$) reduction of 28% from those measured during the dry season. The reduction was primarily the result of storm water wash-off, though there was a slight uptick in operational tempo during the summer that may have resulted in additional deposition.

Particle loading was significantly reduced on the western half of the pier once the surface cleaning BMP was implemented. Values dropped to between ~ 0.4 and 0.9 g m^{-2} and averaged 0.69 g m^{-2} where the cleaning was performed (Table 1, Figure 4). In contrast, loading on the eastern (uncleaned) half of the pier ranged between ~ 1 and 4 g m^{-2}, and averaged 2.29 g m^{-2}. The surface cleaning therefore resulted in a statistically significant ($p=0.05$) reduction in particle loading of 70%.

5.1.2 Pier 7

Particle loading measurements made throughout the demonstration period on Pier 7 are shown in Figure 5 (full data set can be found in Appendix D). The time series data show relatively higher loading levels, higher variability, and larger differences between the two halves of the pier than was observed for Pier 2. The loading and variability were consistent with the changing level of operational activities occurring on the pier, including pier concrete surface repair work that started in September. Wet season values on the pier were lower as was observed on Pier 2. Similar to Pier 2, values ranged between ~ 1.5 and 4 g m^{-2} at the start of the wet season and decreased near the end of March after a relatively large (0.64 inch) storm event. The average particle loading over the entire Pier 7 during the first wet season was 2.54 g m^{-2}, a value that was slightly lower than measured on Pier 2 (Table 1, Figure 4). Particle loading on the pier increased into the dry season when considerably more variability was observed, and levels that commonly ranged between ~ 5 and 7 g m^{-2} had a maximum of 9.5 g m^{-2}. The spike in loading was coincident with the observation of dust and debris generated by concrete repairs primarily on the eastern end of the pier. The average dry weather particle load was 5.38 g m^{-2} over the entire pier. The average wet weather values represent a statistically significant ($p=0.05$) reduction of 53% from those measured during the dry season. In this case, the seasonal change came about from a combination of both storm water wash-off in the wet season and an increased deposition in the dry season with higher ship activity and the repair work.

Particle loading on Pier 7 was significantly reduced on the western half of the pier once the surface cleaning BMP was implemented. The drop appeared more pronounced than on Pier 2 but that was partially due to the effects of the repair work. Values dropped to between ~ 1 and 2 g m^{-2} during the first three months of the second wet period before increasing during the last two months. The average loading where surface cleaning was conducted was 2.15 g m^{-2} (Table 1, Figure 4). It is not clear why there was a solid increase in loading on this BMP portion of the pier during the last two months of

the period, though the concrete repair work limited access at times and affected where cleaning could be conducted. Loading on the non-cleaned eastern half of the pier ranged between ~4 and 7 g m^{-2}, and averaged 4.38 g m^{-2}. The large drop in loading seen in mid-February may have been a result of cleanup associated with the repair work. The average reduction of 51% from surface cleaning of this pier was statistically significant (p=0.05). The effectiveness of the surface cleaning BMP on this pier was affected by the variation and location of the activity level.

5.1.3 Pier 13

Particle loading measurements made throughout the demonstration period on Pier 13 are shown in Figure 6 (full data set can be found in Appendix D). The time series data showed early on generally higher particle loads, higher variability, and larger differences between the two halves of the pier than was observed on the other two piers. Like Pier 7, the loading and variability were consistent with the changing level of operational activities that was very high on the eastern half of the pier at the start of the monitoring period, dropping off to near zero during the summer and again becoming very heavy during BMP implementation. The operational differences resulted in the two halves of the pier having quite different loading levels in the first wet season. Values ranged between ~ 2 and 4 g m^{-2} on the western, relatively low activity half of the pier and between ~ 5 and 7 g m^{-2} on the eastern half. Loading increased into the dry season on the western half of the pier similar to the observations on the other two piers and consistent with the effects of wash-off during the wet season. In contrast, the eastern half of the pier showed a slight decrease in particle loading into the dry season consistent with decreasing activity levels. The result was an average particle loading for the entire pier (4.42 g m^{-2}) that was only slightly lower (14%) during the wet season than the average of 5.14 g m^{-2} during the dry season (Table 1, Figure 4). The seasonal change that was statistically significant (p=0.05) for the less active west half of the pier was not observed on the highly active east half.

Particle loading on Pier 13 was reduced on the eastern half of the pier once the surface cleaning BMP was implemented. The drop was not as pronounced and the levels were more variable than observed on the other two piers. Values were commonly between ~ 2 and 4 g m^{-2} but jumped up to between 4 and 5 g m^{-2} during February and March. This compares with particle loads on the non-BMP half of the pier that ranged between ~ 3 and 6 g m^{-2} in the first part of the period and dropping off to about 2 g m^{-2} toward the end of the period. The average loading where surface cleaning was conducted was 3.06 g m^{-2} compared to 4.43 g m^{-2} on the non-BMP, western end of the pier (Table 1, Figure 4). The average reduction of 31% from surface cleaning of this pier was statistically significant (p=0.05). The effectiveness of the surface cleaning BMP on this pier, similar to Pier 7, was affected by the variation and location of the activity level.

The total mass loading of particles on the piers was calculated by multiplying the average particle loads measured in g m^{-2} by the total surface area of each pier. The average total mass of particles on the piers was calculated for the entire pier for the first wet and subsequent dry season condition, and for each half of the pier for the BMP evaluation period (Table 2). The average particle loads ranged from roughly 40 to 129 kg of particles on each pier (Table 2). The average reduction in particle loads using the surface cleaning control practice ranged between 14 and 20 kg. The reduction values would double if applied to the entire pier.

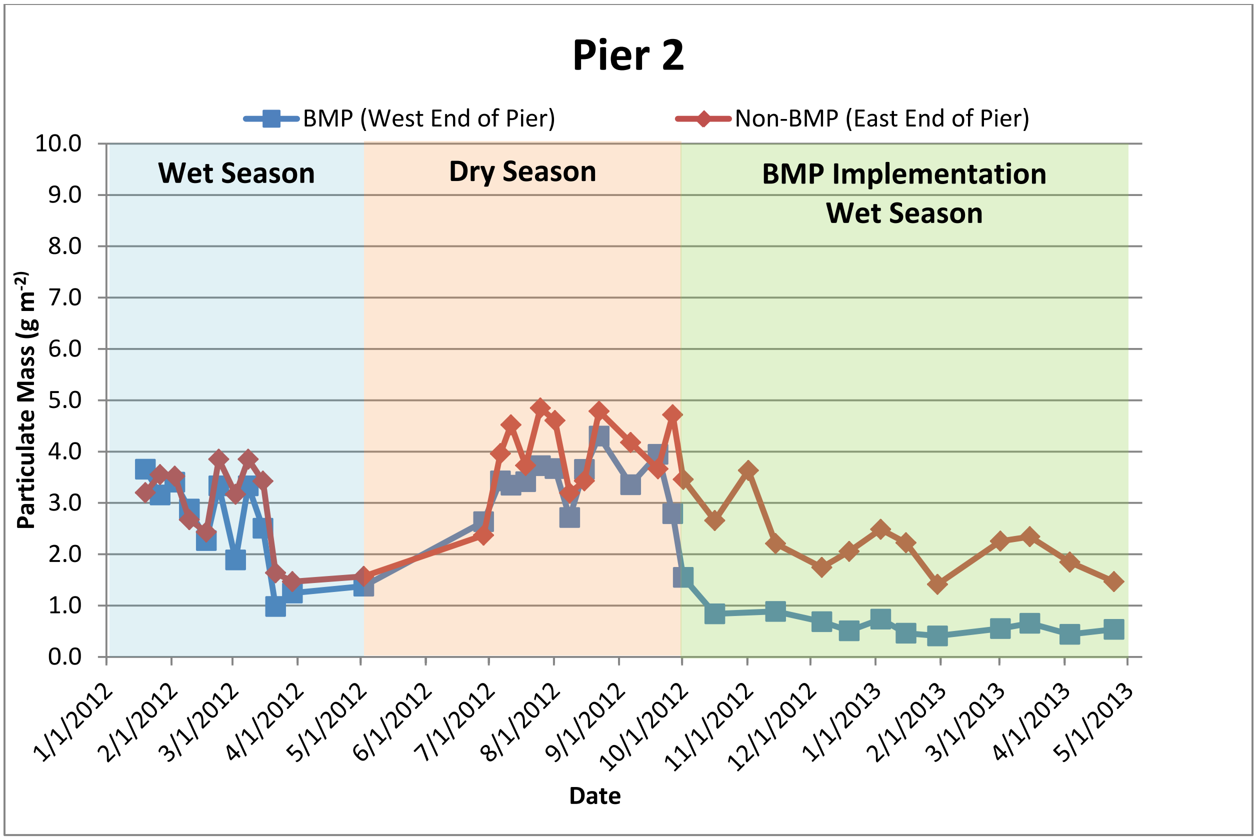


Figure 3. Particle loading measurements made on Pier 2 over the entire demonstration period that covered a wet season, a dry season, and a second wet season when the surface cleaning BMP was implemented on the western half of the pier.

Table 1. Average particle loading (g m^{-2}) and relative standard deviation (RSD) measured in samples collected over the entire pier during the January through April 2012 wet season and the June through September 2012 dry season (n = 24 for each period). The average non-BMP and BMP particle loading values were based on 12 or 14 measurements made on half of each pier during the October 2012 through May 2013 wet season.

Evaluation	Pier 2			Pier 7			Pier 13		
	n	Average (g m^{-2})	RSD (%)	n	Average (g m^{-2})	RSD (%)	n	Average (g m^{-2})	RSD (%)
Wet	**24**	2.68	34	**24**	2.54	31	**24**	4.42	41
Dry	**24**	3.71	19	**24**	5.38	25	**24**	5.14	17
Seasonal Reduction		**28%**			**53%**			**14%**	
Non-BMP	**12**	2.29	29	**14**	4.38	27	**14**	4.43	21
BMP	**12**	0.69	45	**14**	2.18	57	**14**	3.06	39
BMP Reduction		**70%**			**51%**			**31%**	

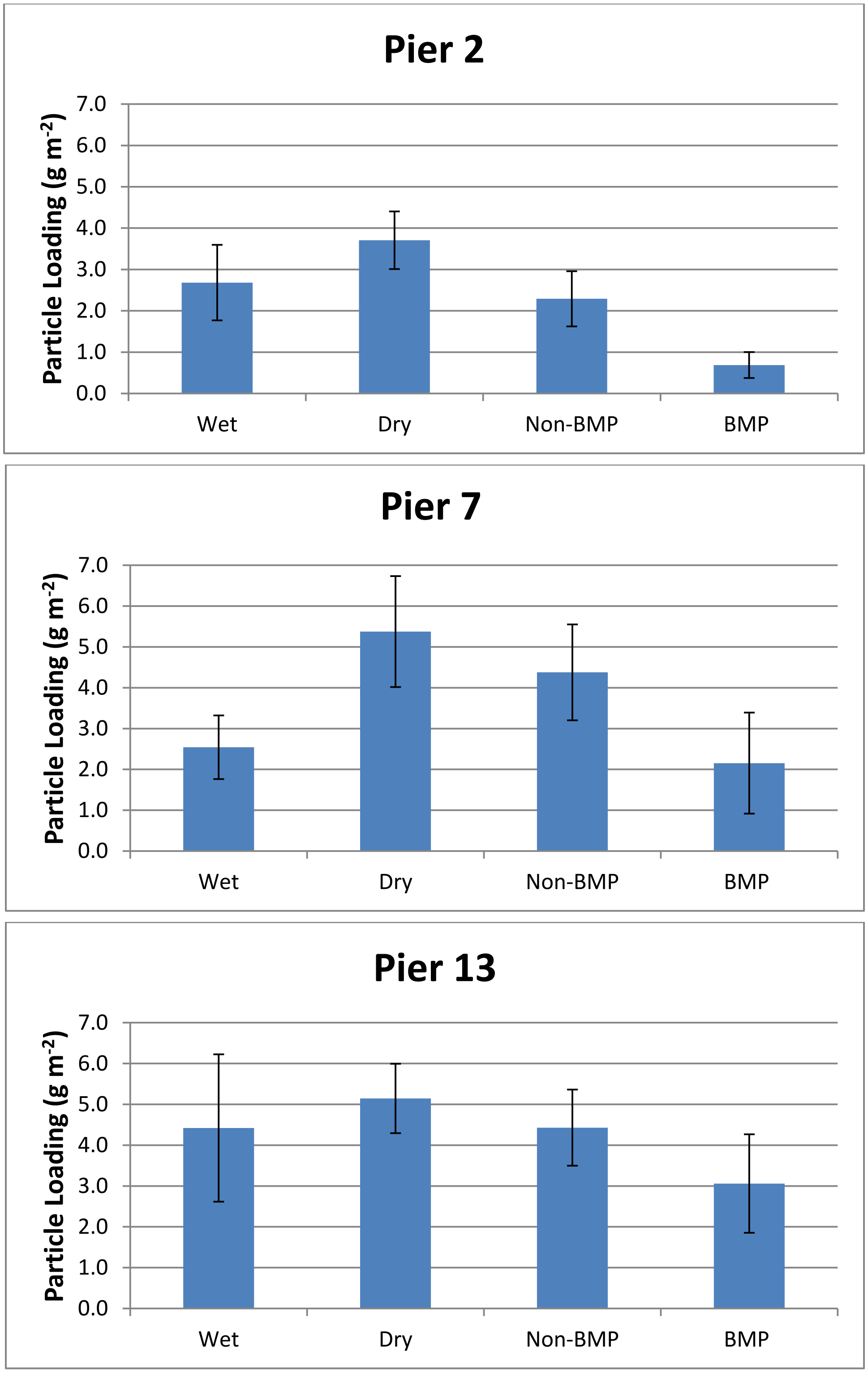


Figure 4. Average particle loading (g m^{-2}) and standard deviations measured on Piers 2, 7, and 13 during the first wet season, dry season, and the second wet season when the surface cleaning BMP was implemented (see Table 1).

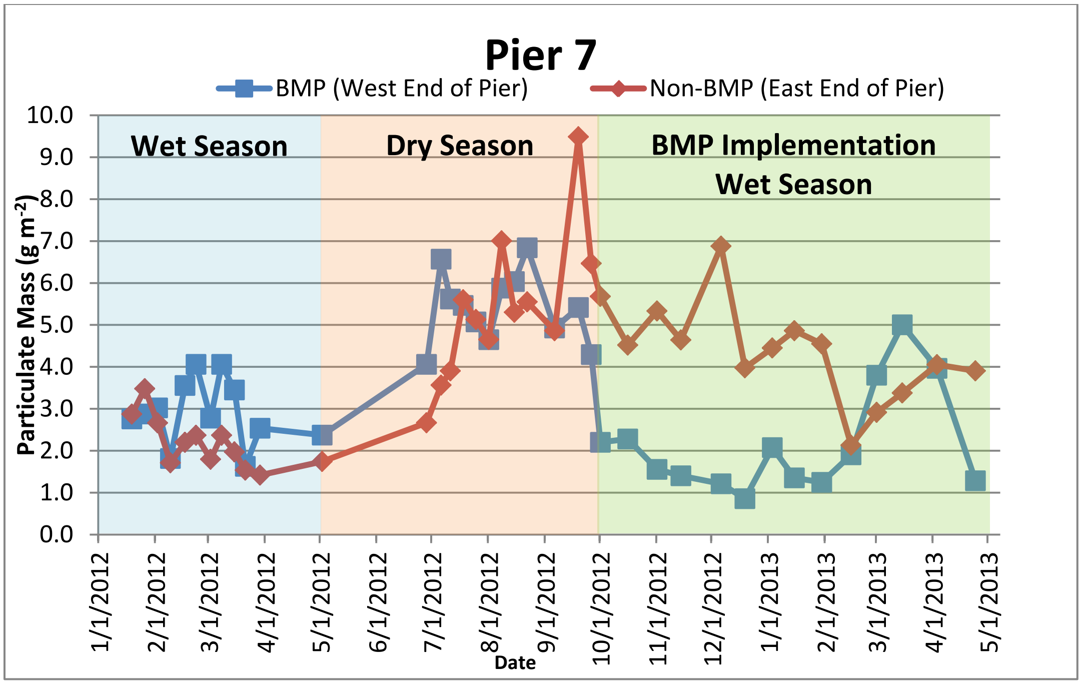


Figure 5. Particle loading measurements made on Pier 7 over the entire demonstration period that covered a wet season, a dry season, and a second wet season when the surface cleaning BMP was implemented on the western half of the pier.

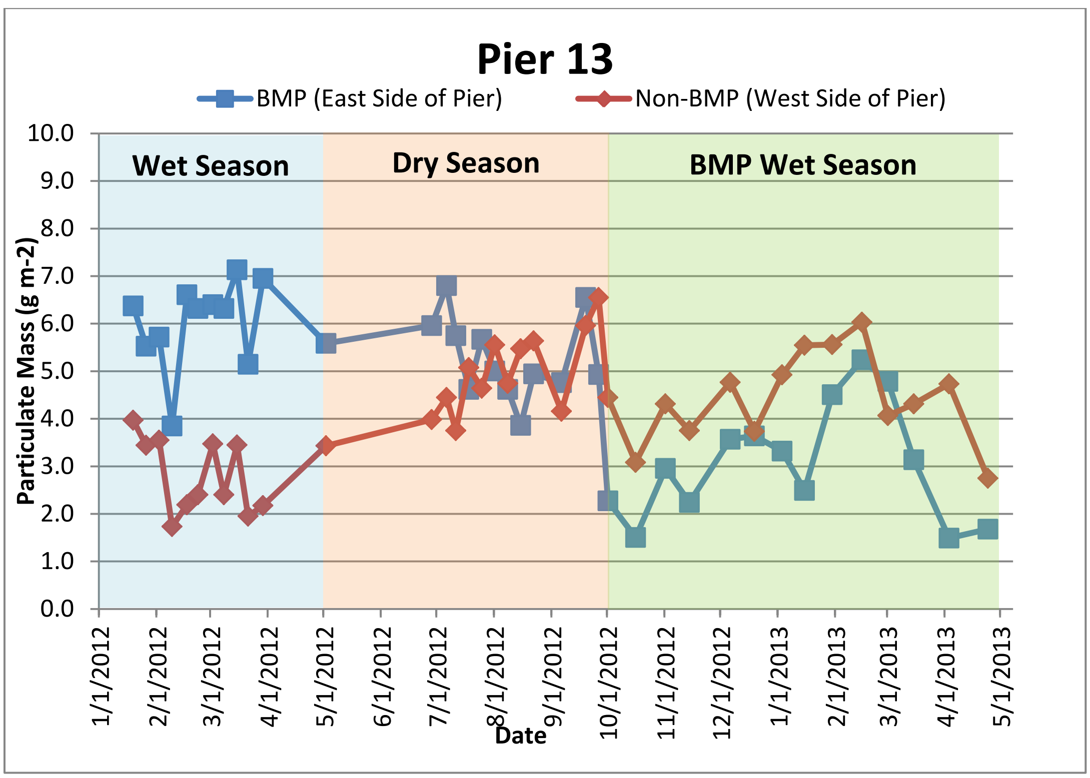


Figure 6. Particle loading measurements made on Pier 13 over the entire demonstration period that covered a wet season, a dry season, and a second wet season when the surface cleaning BMP was implemented on the eastern half of the pier.

Table 2. Total particle mass measured in grams on each pier during wet and dry seasons and on half of each pier during the BMP evaluation period. Values are based on average particle loading (Table 1) and pier surface areas.

Pier	Whole Pier Wet (g)	Whole Pier Dry (g)	Non-BMP (g)	BMP (g)	BMP Reduction (g)
2	47700	65800	21900	7600	14300
7	46700	98600	41400	21100	20300
13	111700	128600	57700	40200	17500

5.2 METAL LOADING

The mass of particle-bound copper and zinc measured on particles collected during the weekly collections is shown in Table 3 and Figure 7 (full data set can be found in Appendix D). On average, particle concentrations of copper were lower than zinc, with a total metal loading that commonly ranged between 100 and 2000 g. Similar to particle loading, copper and zinc loading was higher during the dry season (Pier 13 copper was an exception) than during the wet season. Dry weather loading of copper on Piers 2 and 7 was approximately 50 to 80% higher than during the wet season, while zinc was 2 to 3 times higher. The relatively higher zinc during dry weather may suggest additional sources and/or more dissolution during the wet season. The levels of copper and zinc measured on Pier 13 were similar for both wet and dry conditions, a likely result of the changing activity from high in the wet season to low in the dry season. As large as the observed differences were in copper and zinc loads were in dry and wet conditions, only about half the comparisons were statistically significant, a result of highly variable metal concentration data.

Copper and zinc loads on the piers were considerably reduced when the surface cleaning control practice was implemented. Average copper and zinc loads were approximately 75% and 40% lower, respectively, during BMP implementation (Table 3) While the BMP reductions were substantial, the comparisons of BMP and non-BMP metal data was statistically different only for Pier 13. The lack of statistical significance was again related to the high level of variability measured over time on the piers. Figure 8 shows the relatively lower and consistent metal loading with implementation of surfacing cleaning (primarily for copper). The reduced spiking resulting from the cleaning practice can potentially lead to better storm water results over time given the random nature of operational activities and rain events.

5.3 PARTICLE SIZE

The size distribution of particles collected from the weekly vacuuming was measured to evaluate which particle sizes may be contributing most to the pier loading and how effective the surface cleaning was at removing them (full data set can be found in Appendix D). The distribution was binned into four size categories as shown in Figure 9. The particle size distribution on Pier 2 before BMP implementation was relatively uniform, with each fraction making up between 22 and 28% of the non-BMP distribution. After BMP implementation, there was a slight shift into the two smaller size fractions (~ 8% overall), indicating that the surface cleaning was more efficient at removing the larger size particles, a result that is commonly observed in other sweeping studies (Breault, Smith and Sorensen, 2005; Pitt, Bannerman, and Sutherland, 2004; R. J. Waschbusch, 2003).

Table 3. Average particle copper and zinc mass measured on each pier during wet and dry seasons and on half of each pier during the BMP evaluation period. Values are based on average particle loading (Table 1), pier surface areas, and copper and zinc concentrations measured on particles. All values are in grams.

Pier 2 Cu	Wet (g)	Dry (g)	Non-BMP (g)	BMP (g)
Min	48	171	5.2	1.0
Max	303	377	773	83
Average	155	243	111	19
Stdev	71	70	214	22
Pier 2 Zn				
Min	55	152	10	2.3
Max	261	1243	124	94
Average	145	488	38	26
Stdev	64	376	39	33

Pier 7 Cu	Wet (g)	Dry (g)	Non-BMP (g)	BMP (g)
Min	72	138	16	9.8
Max	219	779	801	98
Average	156	285	114	36
Stdev	40	176	195	25
Pier 7 Zn				
Min	84	263	16	6.8
Max	1040	1712	137	118
Average	325	697	48	33
Stdev	246	535	30	30

Pier 13 Cu	Wet (g)	Dry (g)	Non-BMP (g)	BMP (g)
Min	205	102	69	29
Max	530	430	1380	131
Average	332	261	282	73
Stdev	102	106	333	35
Pier 13 Zn				
Min	290	295	88	26
Max	1653	2143	317	135
Average	741	716	145	65
Stdev	382	580	70	30

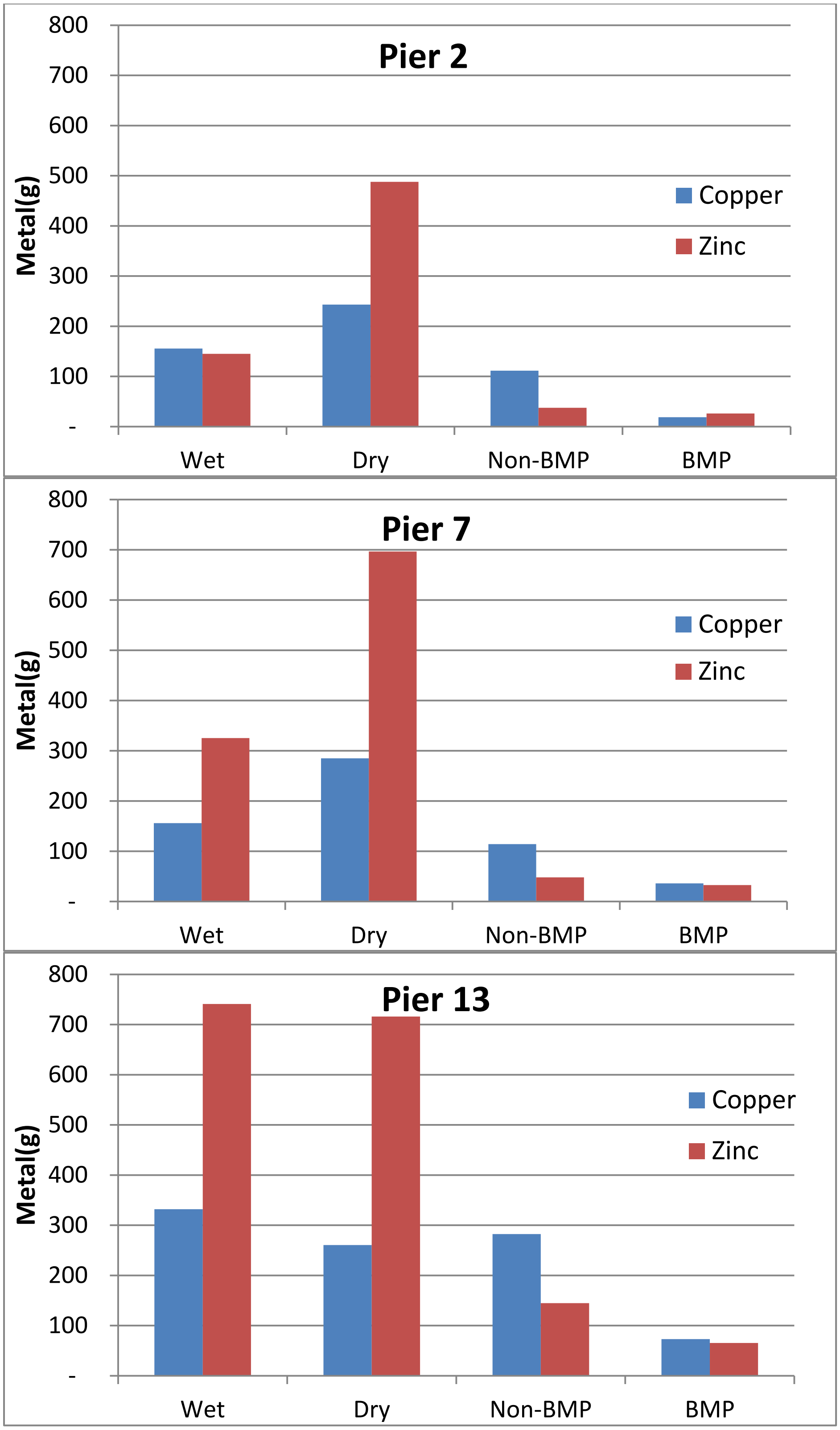


Figure 7. Average copper and zinc mass measured on each pier during wet and dry seasons and for half of each pier during the BMP evaluation period.

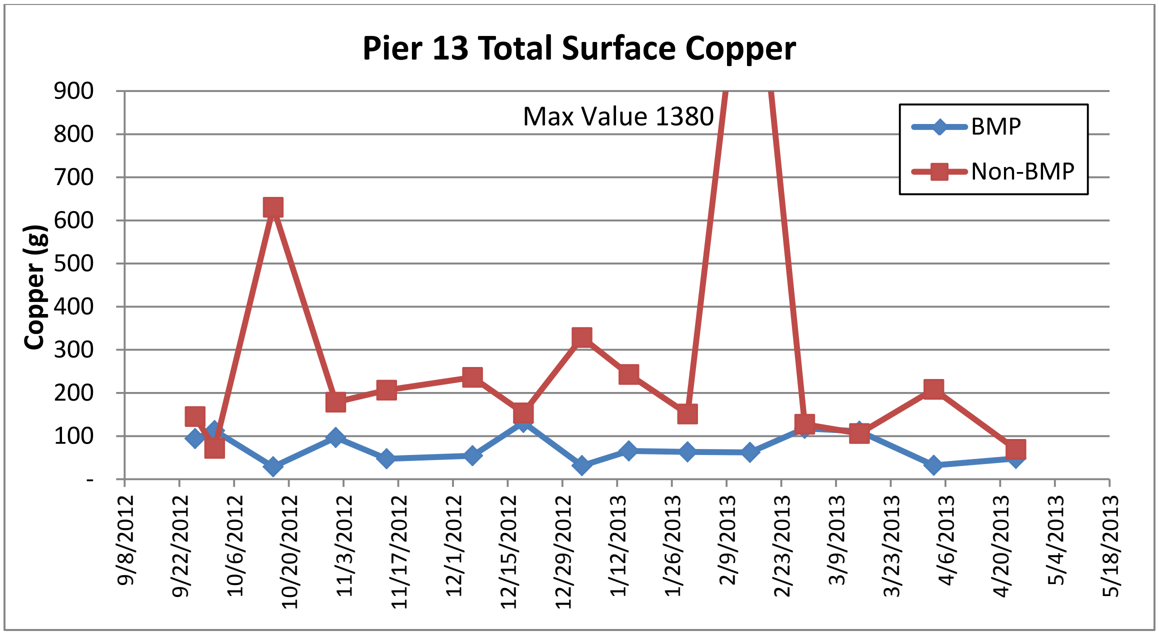


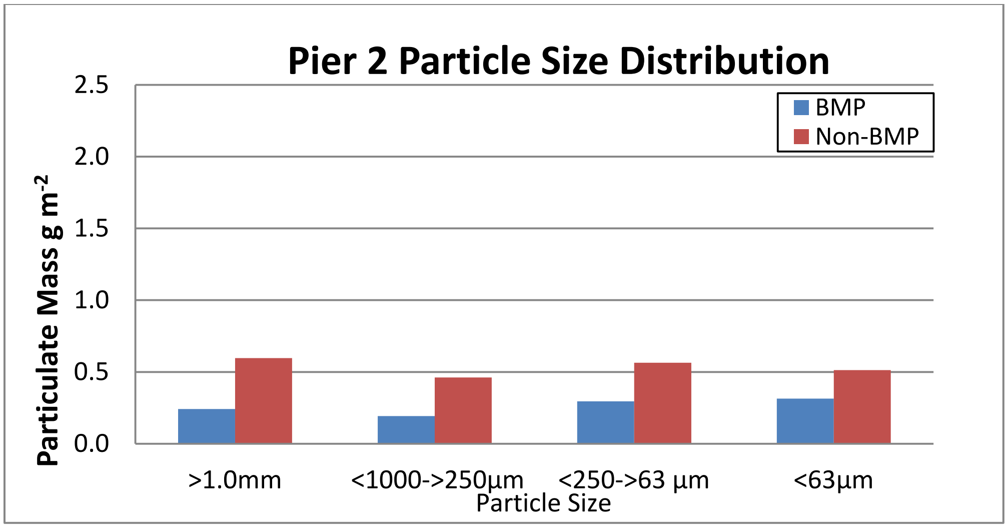
Figure 8. Total pier copper loading on Pier 13 during the BMP implementation period. Copper levels were more consistent and lower with surface cleaning than without it, a result that was observed on all three piers.

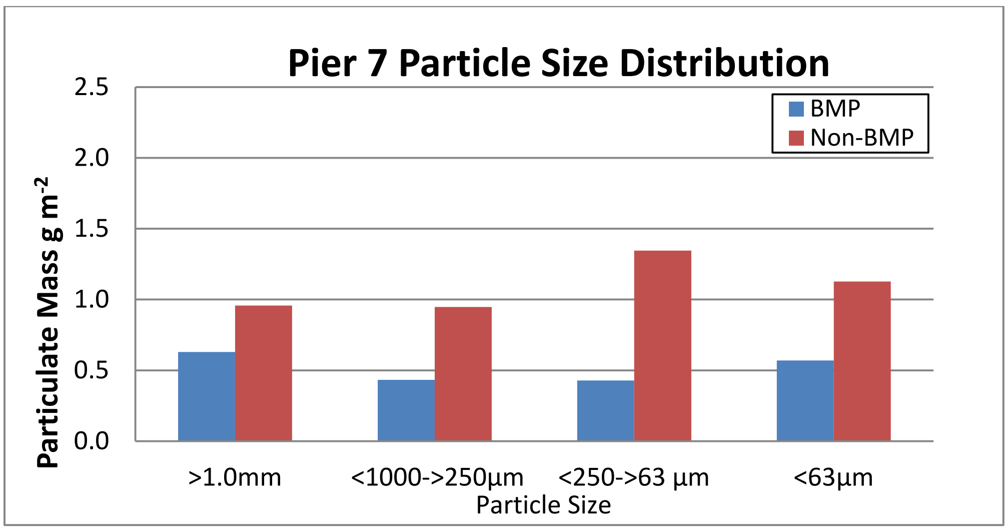
The particle size distribution on Pier 7 before BMP implementation showed a slight trend of increasing mass in the two smaller size fractions. The fractions ranged from 22% for the two smallest size fractions up to 31% in the 63- to 250-µm size bin. Application of the surface cleaning resulted in shifts to both the 63- to 250-µm and the > 1.0-mm size bins. In this case the surface cleaning was less effective in removing the largest particles and more effective in the 63- to 250-µm size range.

The particle size distribution on Pier 13 before BMP implementation showed a clear trend of increasing mass into the smaller size bins, with the largest amount (47%) falling in to the 63- to 250-µm size bin. Implementation of the surface cleaning had almost no effect on the distribution suggesting that the BMP was effective across all size classes. The observed differences in effectiveness of the cleaning practice at removing different particle size fractions likely played a role in the overall effectiveness of the BMP but the reason(s) for the variability are not possible to derive from the dataset.

5.4 METALS AND SIZE DISTRIBUTION

Average copper and zinc concentrations associated with five particle size fractions collected from all piers are shown in Figure 10. In general, copper and zinc concentrations increase with decreasing particle size. Also, particle concentrations of zinc are higher than copper for each size fraction. Particle copper concentrations ranged from about 1500 to 4500 µg g^{-1} while zinc ranged from about 2100 to 7000 µg g^{-1}. The increase in metal concentrations with smaller size fractions is consistent with other studies (Breault, Smith, and Sorensen, 2005; Grant et al., 2003).





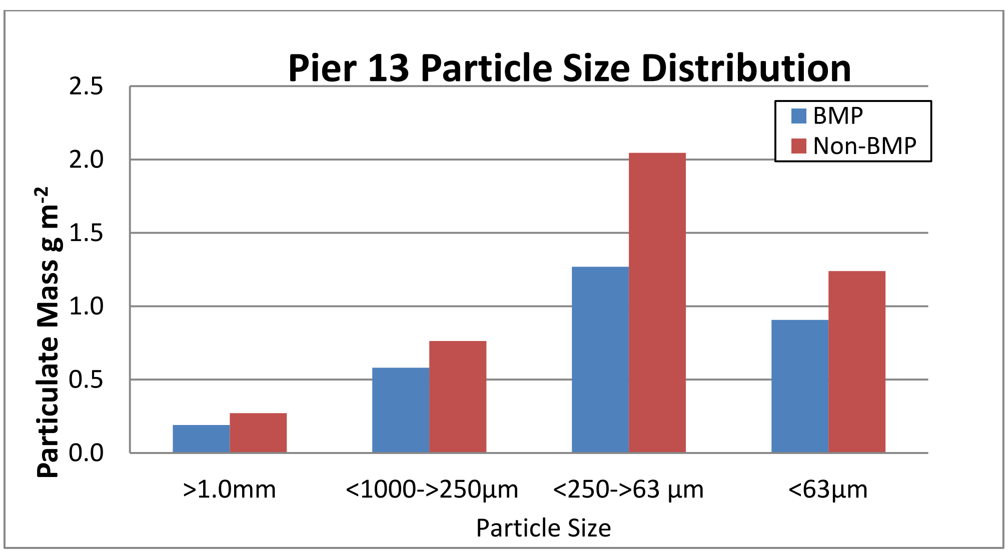


Figure 9. Average particle size distribution for samples collected during weekly vacuuming on each pier during the BMP implementation period. The data are separated into BMP and Non-BMP.

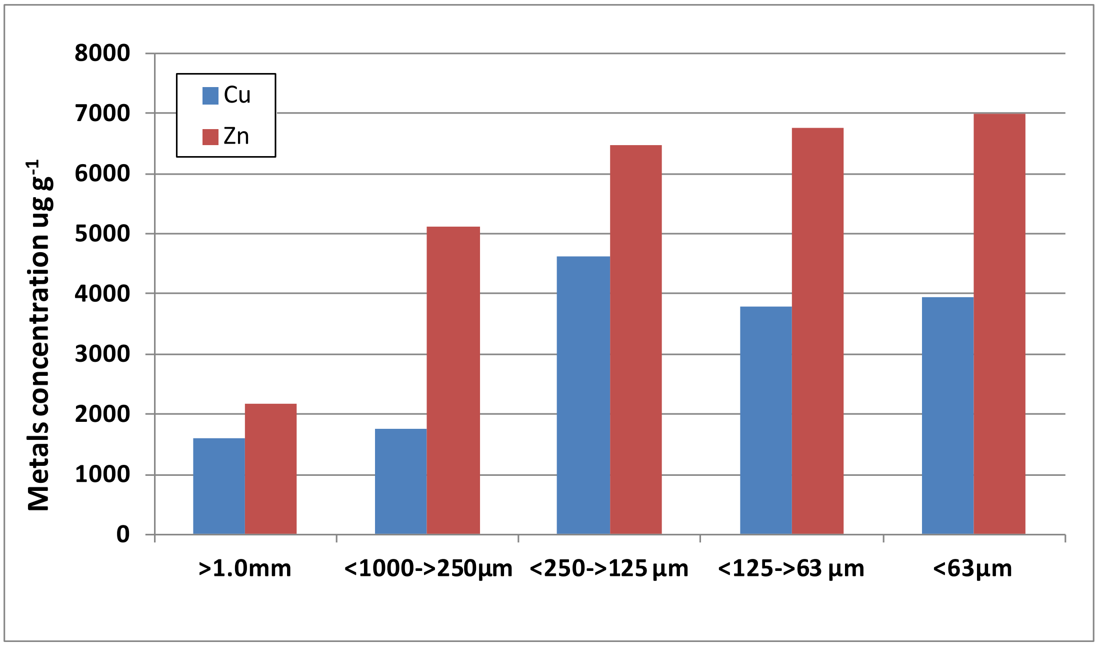


Figure 10. Average copper and zinc concentrations associated with five different size fractions. Data are averaged from samples taken from all three study piers.

5.5 STORM WATER

Total copper, zinc, and toxicity results for storm water samples collected during the BMP implementation period are shown in Table 4 and Figure 11. Drains on each half of the three piers were sampled during three storm events in January, February, and May 2013 as part of the Naval Base NPDES permit monitoring program. Total copper concentrations ranged between 24 to 76 µg L^{-1} on Pier 2, between 49 and 300 µg L^{-1} on Pier 7, and between 180 and 1000 µg L^{-1} on Pier 13. The relative storm water concentrations on each pier were consistent with the relative particle and metal loading levels. Total copper concentrations showed statistically significant reductions in storm water collected from the cleaned half of all three piers when evaluated for all storms and piers (n=9). However, two of the three sampling events showed slightly higher copper on the cleaned half of Pier 2 than on the half that was not. The differences relatively small given normal variability of storm data and particularly given the nature of first-flush sampling protocols. Surface cleaning had the largest effect (factor of 4) in reducing copper concentrations when the loading levels were highest on Pier 13.

Total zinc concentrations ranged between 390 to 1200 µg L^{-1} on Pier 2, between 210 and 3500 µg L^{-1} on Pier 7, and between 820 and 6000 µg L^{-1} on Pier 13. The relative storm water concentrations were generally consistent with the relative particle and metal loading levels. Total zinc concentrations showed substantial reductions in storm water collected from the cleaned half of all three piers when evaluated for all storms and piers (n=9), though the reductions were not statistically significant. Like copper, two of the three sampling events showed slightly higher zinc levels on the cleaned half of Pier 2 than on the half that was not. It is not known why this would occur given the loading data, though at least on the second storm, zinc concentrations were approaching a lower limit for storm water data. Like copper, surface cleaning reduced zinc metal concentrations by up to a factor of 4, in this case, on Pier 7.

National Pollutant Discharge Elimination System permit requirements for NBSD changed during the execution of this surface cleaning project. Previous permit conditions required meeting a copper and zinc benchmarks of 67 and 113 µg L^{-1}, respectively, as well as an acute toxicity result of 90% survival or greater, 50% of the time. Implementation of the surface cleaning BMP was insufficient to consistently meet these permit requirements on all piers during the three evaluated storms.

New storm water NPDES requirements for NBSD (and soon for all metro bases in Navy Region SW) include meeting a facility-wide annual average NAL of 33.2 and 260 µg L^{-1} for copper and zinc, respectively, as well as an acute toxicity limit of > 40% difference from control for individual samples. Failure to meet these limits requires the facility to conduct further evaluations of the sources, potential control measures, eventually leading to implementation of BAT. Because surface cleaning substantially reduced storm water concentrations of copper and zinc, it can potentially be a useful control practice in helping meet the average annual facility-wide limits for copper and zinc, even if individual storm water samples from the piers rarely met NAL values. A facility-wide evaluation would need to be conducted to determine the potential benefits of this approach in meeting compliance with copper and zinc NALs. This control practice may also provide a means for meeting BAT. Implementation of the cleaning practice improved overall test survival values and would have met compliance with the new acute toxicity requirement 89% of the time, up from 67%. The improved result can potentially be important, given that failure of a single toxicity test requires an additional test before moving to more substantial testing and evaluation.

Note that the storm water sample analyses were for the total metal concentration as required under NPDES permit requirements. Historically, the dissolved metal makes up roughly 50% of a sample's metal concentration (Katz, Rosen, and Arias, 2006). Data currently being collected on common Navy materials under NESDI Project 455 show that many of them leach copper and zinc when contacted with water and impact storm water concentrations. The BMP would not be expected to reduce this component of the runoff though it would reduce any leaching of copper and zinc that would occurs from contacting the particles with storm water.

Table 4. First-flush storm water metals and toxicity results for samples collected as part of NPDES permit monitoring. Concentrations are for the total metal. Acute toxicity values are percent survival relative to controls.

Storm Date	Pier	Cu Non-BMP (µg L^{-1})	Cu BMP (µg L^{-1})	Cu % Reduction	Zn Non-BMP (µg L^{-1})	Zn BMP (µg L^{-1})	Zn % Reduction	Toxicity Non-BMP (% Survival)	Toxicity BMP (% Survival)
1/25/2013	2	49	24	51.0	1000	870	13	80	67
	7	300	66	78.0	3500	470	87	67	100
	13	1000	180	82.0	6000	1100	82	20	68
2/8/2013	2	54	59	-9.3.0	390	550	-41	97	93
	7	140	49	65.0	320	210	34	103	100
	13	580	180	69.0	2400	820	66	0	28
5/6/2013	2	38	76	100.0	510	1200	-135	90	90
	7	200	93	53.0	1100	540	51	97	90
	13	740	220	70.3	4500	2200	51	0	80

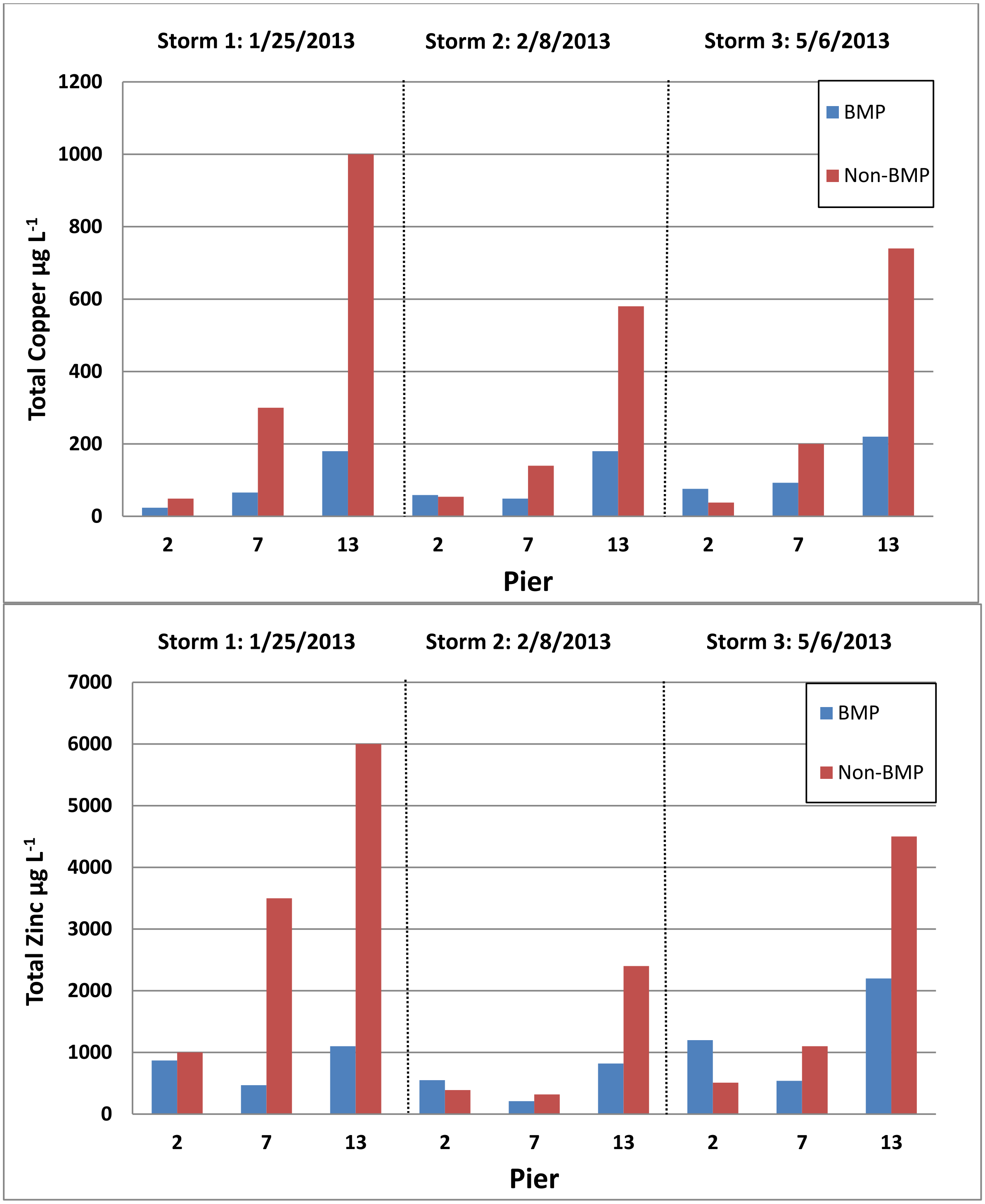


Figure 11. Total copper (top) and zinc (bottom) concentrations measured in storm water samples collected from drains on the cleaned half of the pier (BMP) and from drains on the half of the pier that was not cleaned (Non-BMP).

6. SUMMARY

A surface-cleaning control practice that included weekly power-vacuuming and monthly power-washing was demonstrated on three piers at Naval Base San Diego to evaluate the effectiveness in reducing particle, copper, and zinc loading and in meeting NPDES or TMDL compliance requirements. The effectiveness was validated by collecting and measuring particle samples from random locations on half of each pier where the BMP was applied and comparing them to the amounts collected on the other half of the same pier where the BMP had not been applied.

The results showed that the surface-cleaning control practice decreased the loading of particles, copper, and zinc levels on all three piers under varying operational tempos. The particle load reductions ranged from 31 to 70% and were statistically significant for all three piers (Table 1). On average the cleaning reduced particle loads between ~ 14 and 20 kg on half of each pier (Table 2). The average loading of copper and zinc on the piers was substantially if not statistically reduced by 75% and 40%, respectively. In addition to the overall reductions in loading, implementation of the cleaning control practice appeared to reduce spiking of loads even under increasing operational tempos.

The overall reductions in loading levels that resulted from the surface cleaning were manifested in reductions in storm water copper and zinc concentrations. The reductions were not sufficient to meet historical NPDES permit benchmarks of 67 and 113 $\mu g\ L^{-1}$ for copper and zinc, respectively, nor the acute toxicity requirement for meeting 90% survival. However, the new NPDES permit for NBSD, which will serve as the model for all Navy SW metro permits, uses an NAL approach based on facility-wide average storm water concentrations (33.2 and 260 $\mu g\ L^{-1}$ for copper and zinc, respectively), and meets a toxicity survival value that is no greater than 40% different from control. Implementation of the BMP will result in substantially lower average copper and zinc concentrations, though further evaluation would be required to determine the cost/benefit of utilizing the BMP for regulatory relief. Implementation of the BMP will also likely result in improving the chances of meeting compliance with the new acute toxicity limits.

7. COSTS OF IMPLEMENTATION

The cost of fully implementing the surface cleaning control practice at Naval Base San Diego is provided below in Table 5 and Table 6. The costs are based on the two lowest bids provided by local contractors responding to the request for services proposal shown in Appendix A and conducting the cleaning operations on all 11 piers during weekends. Though it was difficult to complete power-washing on the three half piers in 1 day with one crew, adding crews and equipment, and/or staggering the days for washing (e.g., 1.5 piers/day over eight weekend days/month) would allow sufficient time to clean all 11 piers on a monthly basis.

Surface cleaning costs based on the two lowest bids with weekend rates are shown on a per acre basis in Table 5. The estimated cost of full implementation on NBSD piers over a 9-month September through May rainy season is ~ $150K to $750K/year (Table 6). The total surface area of the 11 piers at NBSD is 26.6 acres (Note: The costs are based on total surface area of the piers though the total area is not actually cleaned because of laydown and other structural impediments).

The costs of implementation of surface cleaning to reduce contaminant loading needs to be evaluated against the potential costs of conducting additional testing, reporting, BAT evaluation, and other costs associated with applying additional treatment BMPs. Recent cost estimates of retrofitting piers at NBSD to divert water for capture and treatment ran about $2M/pier without consideration for additional capital or ongoing costs for treatment[4]. If the BMP could meet BAT requirements, the resulting savings could be substantial. If the BMP is not evaluated as meeting BAT, then its use to meet a time-schedule order to meet BAT may still provide potential benefit to the Base.

Table 5. Two lowest vendor bids to conduct surface cleaning of piers based on statement of work shown in Appendix B. The costs were computed on a per-acre amount for weekend operations.

Cost per Acre	Low ($)	High ($)
Power vacuum	79	134
Power Washing	337	2,643

Table 6. Costs to conduct surface cleaning on 11 piers at NBSD based on weekly power-vacuuming and monthly power-washing. The low and high bids are based on vendor bids shown in Table 5.

	Power Vacuum ($)		Power-Washing ($)		Combined ($)	
	Low	High	Low	High	Low	High
Per Visit	2,096	3,567	8,967	70,262	11,063	73,830
Monthly	8,384	14,269	8,967	70,262	17,351	84,531
Rainy Season (9 Months	75, 460	128,419	80,699	632,362	156,159	760,781
Annual (12 Months)	100,614	171,225	107,599	843,149	208,212	1,014,375

[4] B. Gordon. 2013. Personal communication. Naval Facilities Engineering Command. Region Southwest.

8. LESSONS LEARNED

Some key lessons learned during demonstration/validation included:

1. **Contracting:** Having a well-developed and detailed statement of work to guide the contractor is critical to ensure success. Particular care should be taken to communicate the cleaning goal of removing particles and the differences from a normal street sweeping effort. A site visit by the vendor should be considered, but adding information to the statement of work on how to work in and around laydown and other structural impediments, how/where to block off drains to ensure wash water containment, identify locations for disposal of water and particles, where to acquire wash water, and understanding access will improve the process.
2. **Security.** Vendor costs for security clearances should be specifically included in the bid request. It is important that that base managers ensure that security staff are aware of the operations and their timing.
3. **Waste Removal.** Both particles and water recovered from the piers were tested and identified as potentially hazardous wastes prior to this demonstration. Consideration should be given to their disposal and cost. How often and where the contractor will dispose of collected water and particles will play a role in the final bidding costs.
4. **Pier Structure.** Understanding pier structure was critical as parts of NBSD piers have vaults that open to bay waters below and could not be power washed, thus limiting where the BMP could be applied. These structures need to be identified beforehand to ensure that the vendor does not conduct power-washing over them. Eliminating these areas from power-washing may provide some cost savings.
5. **Work Oversight.** It is important to provide oversight of operations at the start of the contract to ensure all personnel are working under the same understanding of what the level of cleaning is expected and how to work in and around obstacles.
6. **Laydown.** Areas with heavy laydown material such as cables, pipes, etc. may be difficult to clean around. Having the contractor walk over these areas presents an OSHA hazard and it is not feasible to mandate cleaning of these areas. This may limit the total area that can be cleaned (costs) and potentially limit the overall effectiveness of the BMP.
7. **Wash Water Access.** Depending on the truck configuration and number of trucks the contractor may need access to fresh water for use in power-washing activities. Locating a nearby source of freshwater can reduce the time necessary to complete work and keep down costs.
8. **Time to Completion.** Effective cleaning operations can be conducted only during daylight hours. Short daylight hours during the winter storm season should be taken into consideration to ensure completion of operations.

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14. ABSTRACT
The report describes a demonstration to evaluate the effectiveness of a surface cleaning control practice to remove particles, copper, and zinc from Navy industrial areas in an attempt to mitigate these contaminants in storm water runoff. The evaluation was conducted on multiple Navy piers at Naval Base San Diego (NBSD) between 2011 and 2013. The project evaluated the effectiveness of a commercially available power-washing and power-vacuuming service that can be found in most metropolitan areas. The demonstration was conducted under Project 469 of the Navy's Environmental Sustainability Development to Integration (NESDI) Program (http://www.nesdi.navy.mil/).

15. SUBJECT TERMS
particle loading; power-vacuum; surface-cleaning control practice; best technology economically achievable; Naval Base San Diego; power-washing; best management practice; storm water runoff; Navy piers

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